Structure and functions of *Pinus sylvestris* var. *sylvestriformis* plantation ecosystem[1]

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Abstract: Changbai pine (*Pinus sylvestris* var. *Sylvestriformis*) is an endemic and important tree species in Changbai Mountain. There were only 63 plant species in Changbai pine plantation, where hemicryptophyte was dominant(39.68%). Simpson diversity index was 0.87, Shannon-Wiener diversity index was 2.96, and evenness index was 0.82. Community structure were divided into three layers: tree layer, shrub layer and herb layer. The total biomass and net production were 111.982 t/hm^2 and 8942.80 kg/(hm^2· a) respectively. The total biomass for tree, shrub and herb layers were 106.150, 2.230, 2.264 t/hm^2, accounting for 94.79%, 1.99%, and 2.02%, respectively, and net production for those were 7465, 223, and 1182 kg/(hm^2· a), accounting for 83.47%, 2.49%, and 13.22% of the total respectively. The nutrient content in various organs is in the order of needle> branch> root> bark> trunk, For the assimilated organ, the nutrient content is in the order of N> K> Ca> P> Mg, and that in absorption organ is in the order of Ca> N> K> P> Mg. For the whole plantation ecosystem, nutrient content is in the order of soil> litter> herb layer> shrub layer> tree layer. Nutrient storage and its accumulation rate in tree layer take up 88.79% and 76.43% of the total, respectively.

Key words: Structure, function, *Pinus sylvestris* var. *Sylvestriformis*, Plantation

Introduction

Changbai pine (*Pinus sylvestris* var. *sylvestriformis*) which is a rare tree species is endemic in Changbai Mountain. The area of its natural distribution is very limited, only about 200 hm^2 on northern slope of Changbai Mountain. However, Changbai pine as an important tree species has many excellent natures, such as fast growing, straight trunk, good wood and so on. It is called "Beauty Pine". Since 1960's, many Changbai pine plantations have been planted. We conducted studies on structure and functions of the plantation ecosystem, and hoped to set a scientific basis for managing Changbai pine plantation.

Site and Methods

Natural conditions

Survey region is located at southern slope of Jilinhada Mountain(42°31′ N, 125°25′ E), Dayang Forest Farm in Dongfeng County, Jilin Province, with altitudes of 350~450 m. Soil is brown forest soil. Its climate zone is continental monsoon region, cold and drought in winter, warm and moist in summer. Based on climate data of Dongfeng county from 1957-1980, its annual mean temperature is 4.2 °C. The mean temperature of January is -17.5 °C, and that of July is 22.2°C. Annual precipitation is 665 mm, and 64% of precipitation occur from June to August. Warmth index （WI） is 66.7℃ • month, coldness index （CI） is -77.0℃ •month, humidity index (HI) is 9.83 mm/°C • month. In this region, zonal climax community is mixed forest of *Pinus koraienses, Abies holophylla* and *Carpinus cordata* , etc.. However, it is intensive human activity that makes Changbai pine endemic. Changbai pine plantation was planted on the site of *Quercus mongolica*. Its area is 100 hm^2. Its initial density was 4400 stems/hm^2, and actual density is 2100 stems/hm^2 now. In tree layer, mean tree height is 10.8 m, and mean diameter of stem at breast height is 12.0 cm. In shrub layer, the main species are *Corylus heterophylla, Lespedeza bicolor,* etc.. In herb layer, main species are *Carex callitrichos, Carex lanceolata, Artemisia mongolica* and *Pteridium aquilinum*.

Study methods

Three 20 m × 20 m sample plots were set and the dimensions of each tree were measured in Changbai pine plantation. The biomass and productivity were established based

on relative growth method. Shrub and herb layers were surveyed by quadrat-harvesting method (2 m ×2 m for shrubs and 1 m × 1 m for herbs). The formula $W = aD^b$ was used to calculate relative growth where W = biomass, a and b are parameters, D = diameter at breast height. The distribution and accumulation pattern of nutrient elements was studied by routine method.

Results and analysis

Phytocoenology

Compositions and abundance of species

According to statistic data of 3 quadrats in Changbai pine plantation, there are 63 species plants, belonging to 53 genera and 30 families, of which, Compositae takes up 19%, Rosaceae takes up 10%, Liliaceae, Gramineae, Violaceae, Fabaceae and Silenoideae take up 5%, respectively. Simpson index is 0.81, Shannon-Wiener index 2.96, rate of species meeting 0.82, and species regular degree is 0.80. The dominant species under forest varies with different sites. On southern slope the dominant plants are drought-tolerant, such as *Carex callitrichos*, *Artemisia rubripes*, *Leibnnitzia anandria*, *Atratylodes japonica*, *Iris dichotoma*, *Pteridium aquilinum*, etc.. On northern slope, those are *Carex sideroticta*, *Polygonatum odoratum*, *Viola mandshurica*, *Viola acuminata*, *Convallaria keiskei* and others. Many accompany species were introduced due to

human activities, such as *Bidens parviflora*, *Setaria viridis*, *Arthraxon hispidus* and *Plantago asiatica*.

Growth situation and density management

On standard site, a 24-year-old tree, 12.7 m in height and 14.7 cm in DBH, was selected. Its growth process is shown in Table 1.

Table 1. Growth process of single tree of Changbai Pine

Tree age /a	Height growth /m			Diameter growth /cm		
	total	mean	annual	total	mean	annual
5	0.75	0.15	0.45	0.38	0.08	
10	4.00	0.40	0.65	2.58	0.26	0.50
15	7.40	0.49	0.65	5.98	0.40	0.70
20	10.45	0.52	0.85	10.40	0.52	0.94
24	12.70	0.53	0.40	14.70	0.61	1.48

After 6 years, diameter growth rate was increasing. However, height growth is slow before 5-year-old, and increases gradually afterward. Generally, annual height growth is about 50~75 cm, and the maximum is about 85 cm.

In order to evaluate objectively growth situation of Changbai pine plantation, we developed comparative study on *Larix olgensis* and *Pinus koraiensis* (Table 2) which proved that Changbai pine is a fast growing tree species

Table 2.   Comparison of growth among Changbai Pine and other coniferous species

Sites	Tree species	Age /a	Height / m	%	DBH /cm	%
Dayang	*Pinus sylvestris* var. *sylvestriformis*	18	8.80	100.00	10.80	100.00
Dabeicha	*Pinus sylvestris* var. *sylvestriformis*	18	9.06	102.95	10.38	96.11
Daboji	*Larix olgensis*	18	9.70	110.23	9.90	91.67
Renao	*Pinus koraiensis*	18	4.83	54.89	6.70	62.04

There is a close relationship between artificial managed density and initial forest density. According to Kira's -3/2 rule and Rdineke's study, we had model of maximum density of Changbai pine plantation, which is $\log N$ = $1.1686 \log D + 4.5835$. Therefore, tree number on unit area in Changbai Pine plantation decreases with mean diameter of stand increasing(Table 3).

Table 3. Relationship between density and mean diameter of trees

Mean diameter /cm	Density /stem· hm^{-2}
8	3400
12	2100
16	1500
20	1100
24	900
28	750

There are different targets on density management of plantation. Generally, middle class density is fit for

Changbai Pine plantation.

Feature and structure of community

Community appearance: Characteristics of community appearance are determined by its life-form. According to classification system of Raunkiaer, we grouped the life-form in Changbai pine plantation (Table 4), where Hemicryptophyte takes up 39.68%, Geophyte takes up 26.98%. It is similar with Changbai pine natural forest, but it is different from other forest types.

Community structure: Obviously, Changbai pine plantation can be grouped into three layers: tree layer, shrub layer and herb layer. Tree layer is composed of *Pinus sylvestris* var. *sylvestriformis* almost alone, taking up about 90%. The trees about 10~14 cm in DBH is dominant, taking up 57%.

In shrub layer, Phanerophyte is a superior synusia. The main species include *Corylus heterophylla*, *Lespedeza bicolor*, seedlings of *Tilia mandshurica* and *Ulmus japonica* which is affected by human activity.

In herb layer, Hemicryptophyte is superior, where *Carex callitrichos* is dominant. Geophyte is second synusia. Main species are *Asparagus oligoclonos, Smilacina japonica, Polygonatum aquilinum* et al; Annual plants are *Setaria viridis, Bidens parviflora, Artemisia scoparaia*.

Table 4. Comparison of life-form among several forest types on Changbai Mountain

Forest type	Life-form %					
	Phanerophyte	Chamaephyte	Hemicryptophyte	Geophyte	Annual	Ultrasynusia
Changbai Pine plantation	17.46	1.59	39.68	26.98	14.29	
Changbai Pine	29.00	4.60	39.70	24.40	2.30	
Broad-leaved Korean Pine	27.27	3.90	38.96	19.48	3.90	6.49
Spruce-fir	23.40	12.77	36.17	23.40	2.13	2.13
Betula ermanni	5.56	16.67	52.94	27.78		

Biomass and productivity

Regression equations

According to relative growth situation, we had functions of biomass related to tree diameter at breast height(Table 5). Where R value (the correlation coefficient) is over 0.9, so the functions are useful.

Distribution of biomass

According to the equations, biomass' distribution of each organ in Changbai Pine plantation can be determined as Table 6-9.

Major biomass of trunk and bark of Changbai Pine is on lower layer. Biomass of trunk under 6 m takes up 82.52%, and that of bark 82.22%. This is economic production of Changbai pine.

Table 5. Regression equations of dry weight of organs and DBH

Item	Regression equations	Correlation coefficient	SSD	DBH
Trunk	$W_t=15.9368D^{2.949}$	0.9721	0.0182	6.8-17.5
Bark	$W_f=630.0862D^{0.759}$	0.9327	0.0176	6.8-17.5
Branch	$W_b=55.7699D^{2.483}$	0.9482	0.0213	6.8-17.5
Leaf	$W_l=0.1090D^{4.293}$	0.9115	0.0568	6.8-17.5
Root	$W_r=200.0322D^{1.495}$	0.9186	0.0602	6.8-17.5
Total	$W_T=317.1758D^{2.024}$	0.9386	0.0431	6.8-17.5

Table 6. Vertical distribution of trunk and bark biomass kg/hm²

Organs		Height /m											Total
		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	-10.8	
Trunk	Biomass	6206	4193	3486	3055	2615	2201	1748	1309	849	475	230	26367
	%	23.5	15.90	13.22	11.6	9.92	8.35	6.63	4.96	3.22	1.80	0.87	100
Bark	Biomass	1322	512	333	288	244	220	195	164	122	83	48	3442
	%	35.8	14.88	9.67	8.37	7.09	6.39	5.67	4.76	3.54	2.41	1.39	100

Table 7. Vertical distribution of branch biomass kg/hm²

Height /m	Layer	Age(year)			Total
		1	2	Several	
9.2~10.8	Upper layer	198.8	162.1	330.7	691.6
		(31.17)	(23.47)	(5.62)	(9.59)
7.6~9.2	Middle layer	206.0	252.6	2322.7	2781.3
		(32.30)	(36.57)	(39.46)	(38.55)
6.0~7.6	Lower layer	233.0	276.1	3233.4	3742.5
		(36.53)	(39.97)	(54.93)	(51.87)
Total		637.8	690.8	5881.8	7215.4
		100	100	100	100

Note: The figure in brackets is percentage

There is a significant difference among different layers on branch biomass distribution. Branch biomass of middle and lower layers takes up 90.42%. As far as age is concerned, biomass of several-year old branch takes up 81.59%. In Changbai Pine plantation, natural and artificial thinning is very intensive.

There is a significant difference among different layers on leaf biomass distribution. Leaf biomass of middle and lower layer take up 80.25%. As far as age is concerned, biomass of one-year old and two-year old leaf take up 83.18%. Needles of Changbai pine fall from third year, and that of four years fall almost.

Table 8. Vertical distribution of leaf biomass kg/hm²

Height /m	Layer	Age (year)			Total
		1	2	Several	
9.2~10.8	Upper layer	585.2	294.2	102.4	981.8
		(24.80)	(16.59)	(12.25)	(19.76)
7.6~9.2	Middle layer	899.2	686.1	311.1	1896.4
		(38.11)	(38.68)	(37.23)	(38.17)
6.0-7.6	Lower layer	875.0	793.5	422.2	2090.7
		(37.09)	(44.73)	(50.52)	(42.08)
Total		2359.4	1773.8	835.7	4968.9
		100	100	100	100

Note: The figure in brackets is percentage

Table 9. Distribution of root biomass kg/hm²

	Fine root	Middle root	Thick root	Large root	Total
Biomass	126.9	804.5	654.3	4948.4	6534.1
Percent	1.95	12.31	10.01	75.73	100

Root system of Changbai pine is very developed and depth can reach 70cm, but most of it distributes between

10 and 40 cm. Biomass of large root takes up 75.73%.

Production structure and productivity
Production structure changes among the vertical distribution of biomass in tree layer, which is useful for understanding function of forest ecosystem.

Table 10. Mean net production in Changbai Pine plantation kg/(hm²·a)

Item	Tree layer	Shrub layer	Herb layer	Litter layer	Total
Net production	7465	223	1182	72.8	8942.8
Percentage	83.47	2.49	13.22	0.82	100

In Changbai Pine plantation, the role of different layers in biomass production is in the order: tree layer> herb

layer> shrub layer> litter layer, and production of tree layer takes up 83.47%.

Table 11. Trees net production in Changbai Pine plantation kg/(hm²·a)

Item	Trunk	Bark	Branch	Leaf	Root	Total
Net production	2307.08	301.21	631.25	3476.67	748.75	7465
Percentage	30.90	4.04	8.46	46.57	10.03	100

The ratio of each organ production in tree layer is needle (46.57%), trunk (30.90%), root(10.03%), branch (8.46%), and bark (4.04%).

Distribution and accumulation of nutrient element

Distribution pattern
Tree layer is main producer in forest ecosystem. In Changbai Pine plantation, there is only one species in tree layer. Mean content of five elements N, P, K, Ca, Mg are

0.2913%, 0.1193%, 0.2625%, 0.3938%, and 0.1305% respectively. Because of significant difference among organs, we treated it in layers (Table 12 and Table 13).

Needles are storage organ, so mean content of nutrients is higher than the whole trees, where N, P are high in one-year old and two-year old leaf, and K, Ca, Mg high significantly in old leaf. Branches are very developed in forest, of which N, P, Mg are very high in one-year old branch.

Table 12. Content of nutrient in branch and needle %

	Element	Age			Height			Mean	Stand death
		One-year	Two-year	Several-year	Upper	Middle	Lower		
	N	1.1278	0.9807	1.0569	1.1361	0.9955	1.0337	1.0551	
	P	0.2210	0.2738	0.0921	0.2285	0.1962	0.1631	0.1956	
Needle	K	0.6062	0.3181	1.2366	0.7615	0.7913	0.6084	0.7203	
	Ca	0.3486	0.5148	0.5083	0.3263	0.4452	0.6001	0.4572	
	Mg	0.1572	0.1881	0.1598	0.1452	0.1435	0.2164	0.1684	
	N	0.5244	0.3437	0.3567	0.4415	0.3909	0.3864	0.4083	0.0462
	P	0.2741	0.2160	0.1165	0.2587	0.2138	0.1347	0.2022	0.0313
Branch	K	0.4898	0.3586	0.4766	0.4955	0.4669	0.3626	0.4417	0.1072
	Ca	0.4985	0.6094	0.4374	0.4608	0.5385	0.5464	0.5151	0.5084
	Mg	0.1812	0.0949	0.1190	0.1514	0.1348	0.1890	0.1583	0.2125

Table 13. Content of nutrient in trunk %

Element	Lower layer		Middle layer		Upper layer		Mean	
	Trunk	Bark	Trunk	Bark	Trunk	Bark	Trunk	Bark
N	0.0073	0.0389	0.0082	0.0742	0.0075	0.0866	0.0077	0.0672
P	0.0098	0.1298	0.0121	0.2270	0.0109	0.1899	0.0109	0.0822
K	0.0412	0.1080	0.0378	0.1527	0.0548	0.1913	0.0466	0.1507
Ca	0.0790	0.7017	0.0782	0.6665	0.0878	0.5278	0.0817	0.6153
Mg	0.0274	0.1132	0.0208	0.1587	0.0723	0.1368	0.0402	0.1362

Nutrient content in trunk is lower than that in bark, and there is little difference in whole trunk. P and Ca in bark is higher than total value in trunk, but N and K are lower. As far as different layers are concerned, N, P, and K in upper layer is higher than that in lower layer. However, Ca and Mg are lower.

The order of nutrient content in Changbai pine plantation is soil> shrub layer> herb layer> litter layer>tree layer. However, as far as storage and accumulation rate is concerned, tree layer is also dominant.

Storage and accumulation of nutrient

Storage of nutrient is determined by accumulation coefficient of plant. In Changbai pine plantation, the order of accumulation coefficient of each element is P> N> K> Ca>Mg. Furthermore, accumulation coefficient of assimilating organ is bigger than non-assimilating organ (Table 14).

Total of all elements accumulation is 148.17kg/(hm^2·a), and the order is N> K> Ca> Mg> P. Accumulation rate of tree layer takes up 76.43%, herb layer18.71%, shrub layer 3.99% and litter layer takes up 0.86% (Table 15).

Table 14.   Accumulated coefficient of plant

Element	Herb		Shrub			Tree			
	Above	Under	Leaf	Branch	Root	Leaf	Branch	Trunk	Root
N	1.669	1.434	2.344	0.969	0.841	2.415	0.935	0.171	0.373
P	2.445	1.572	3.414	4.080	0.806	4.127	4.266	4.074	1.975
K	0.783	0.279	0.368	0.587	0.431	0.430	0.264	0.117	0.076
Ca	0.448	0.544	1.781	0.994	0.623	0.557	0.627	0.849	0.229
Mg	0.460	0.973	0.992	0.232	0.396	0.436	0.410	0.457	0.175

Table 15.   Accumulation rate of nutrient   kg/(hm^2·a)

Element	Litter	Herb	Shrub	Tree					Total
				Root	Trunk	Bark	Branch	Leaf	
N	0.38	8.01	1.35	1.22	0.18	0.20	2.58	36.68	50.60
P	0.02	1.13	0.29	0.70	0.23	0.55	1.28	6.80	11.00
K	0.10	10.51	1.73	0.96	0.95	0.45	2.79	25.05	42.54
Ca	0.63	4.81	2.07	1.41	1.82	1.85	3.25	15.90	31.75
Mg	0.15	3.27	0.47	0.51	0.63	0.41	1.00	5.85	12.28
Total	1.28	27.73	5.91	4.80	3.81	3.46	10.90	90.28	148.17

Conclusions

Changbai pine is a rapid growing tree species. Characteristics of Changbai pine plantation community appearance are similar with its natural forest, but its structure is very simple.

The relationship of organ biomass and DBH was established with relative growth equation $W= aD^b$ instead of $W= a (D^2H)^b$. The regression equations we got are practical.

Biomass and productivity of tree layer in 24-year-old plantation are 106.15 t/hm^2 and 7465 kg/(hm^2·a), which shows the plantation is in rapid-growing period.

Nutrient storage in tree layer is very high, accounting for 88.79%, and its nutrient accumulation rate takes up 76.43%.

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